# Development and Applications of Probabilistic Climate-Change Projections for California

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*US Geological Survey*
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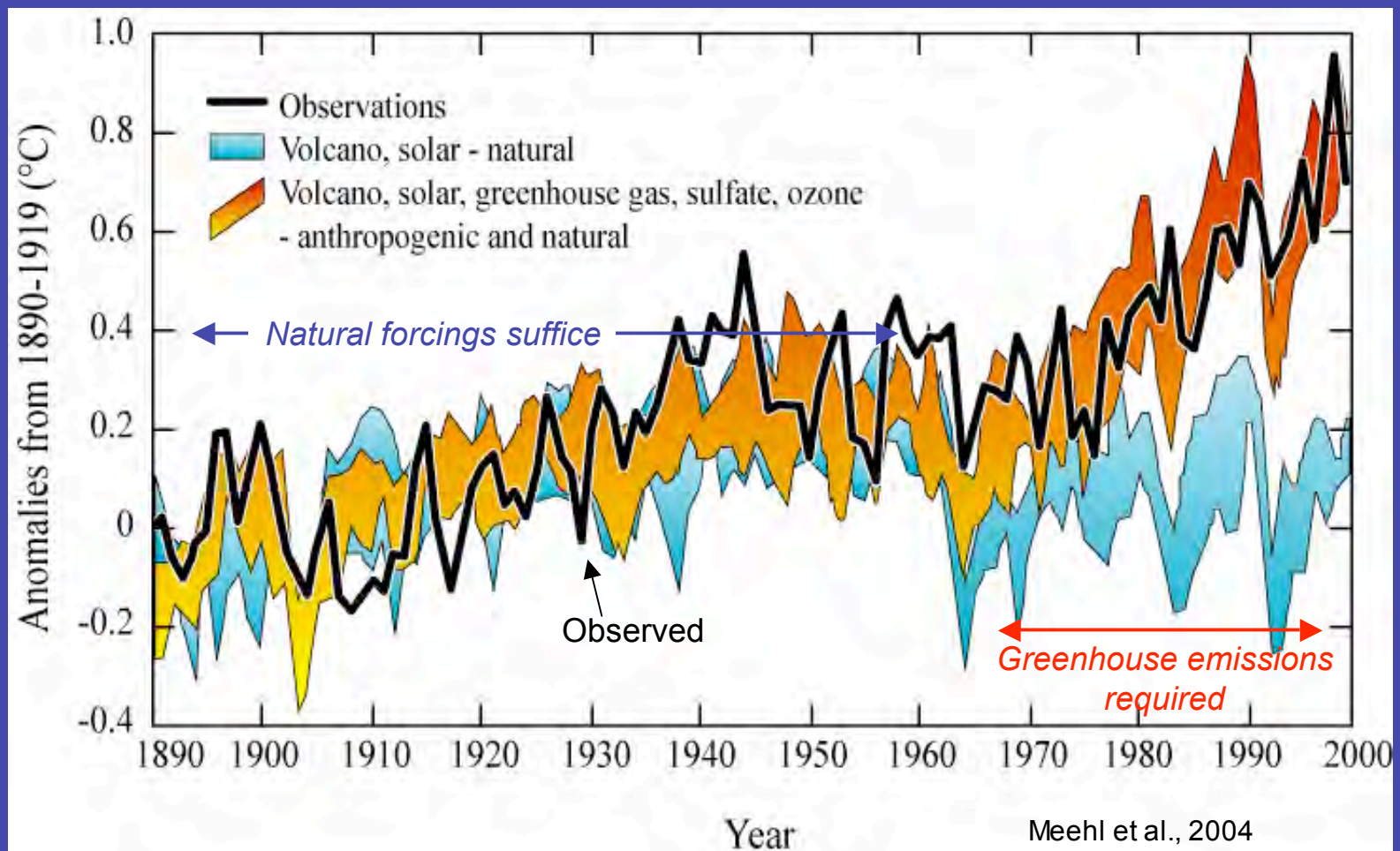*La Jolla, CA*

**Daniel Cayan**
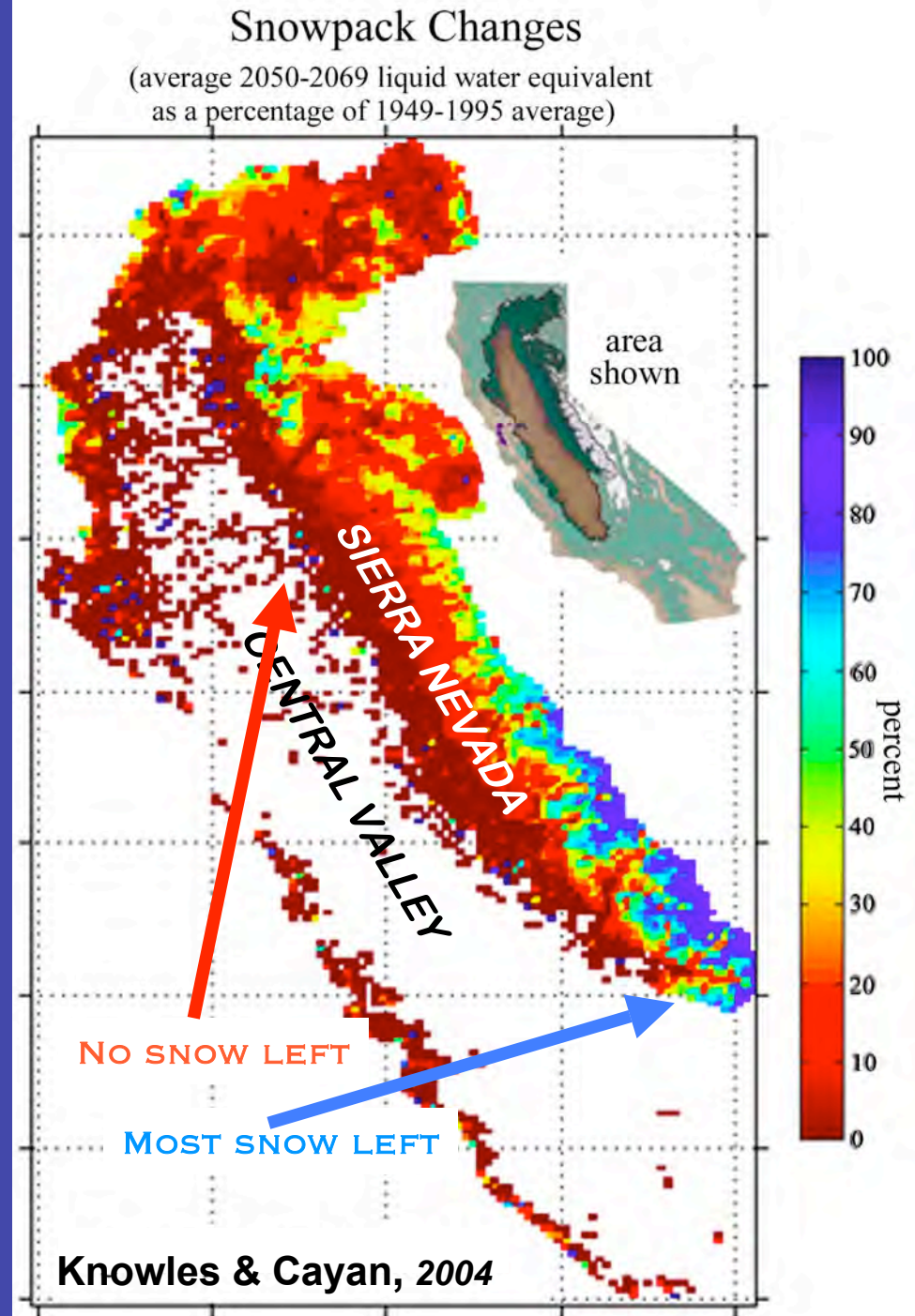*Scripps Inst Oceanography/USGS*
*La Jolla, CA*

USGS

# In recent decades, warming has begun in response to the increasing global greenhouse effect.

*Climate-model simulations of global-average temperature*



Meehl et al., 2004

…and, by the middle of the 21st Century, *even in the coolest of the models*, earlier snowmelts & major reductions in snowpacks and water resources of the Sierra Nevada are projected.



Snowpack Changes
(average 2050-2069 liquid water equivalent as a percentage of 1949-1995 average)

area shown

SIERRA NEVADA

CENTRAL VALLEY

percent

No snow left

Most snow left

Knowles & Cayan, *2004*

# However, the lessons we take from projections continue to be very uncertain…

## 21st Century Western US Climate - Conclusions

### Greenhouse Effect

Rising Temperatures

Rising Sea Level

Less Snow & Snowpack
Early Runoff

More Flooding

Drier Summers

More or Less Precip?

More Certainty

Uncertainty and Beyond

### Paleoclimates

Continued Drought and Flood

20th Century Warming Unprecedented

Natural MegaFloods

MegaDroughts Possible

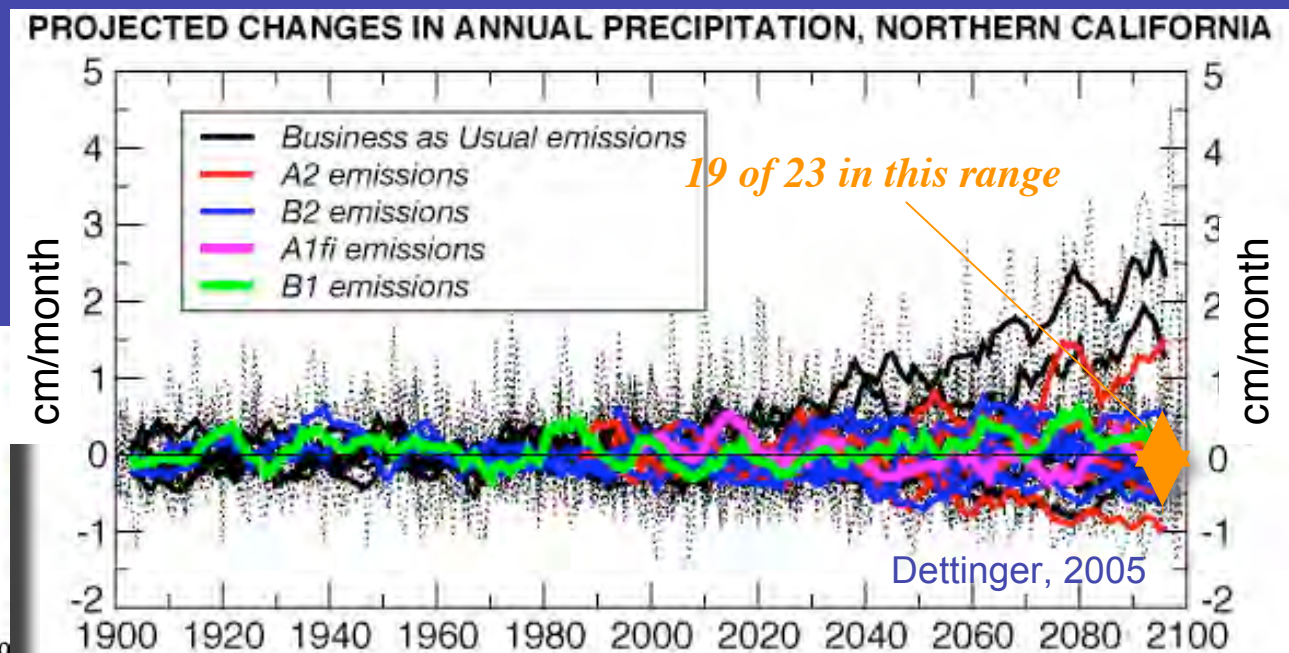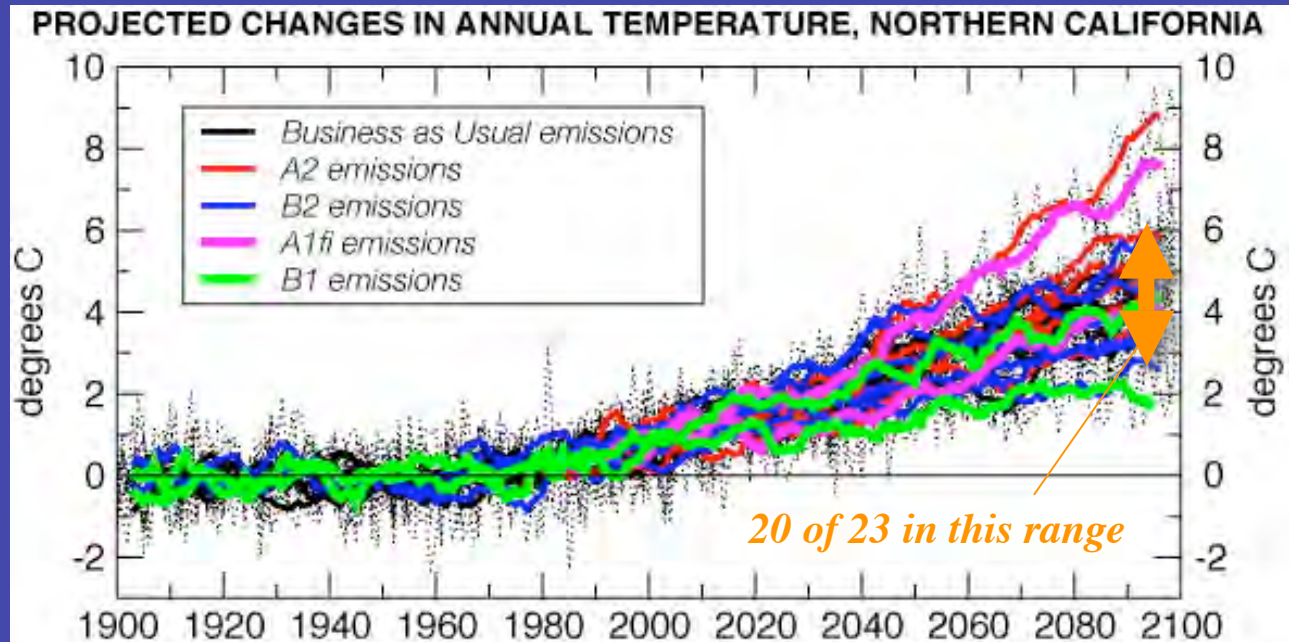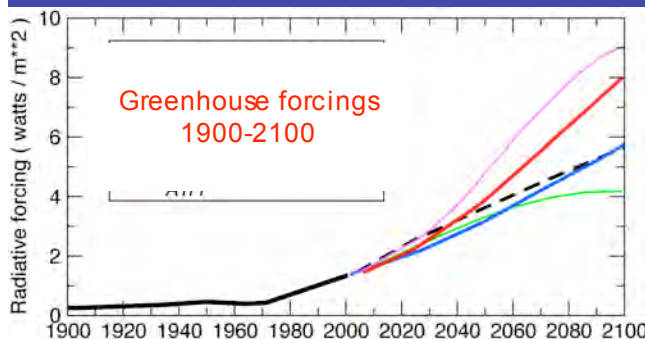20th Century Unusually Benign (wet)

Gradual /Abrupt Change?

USGS

So we are being whipsawed by **near-future** climate projections that are simultaneously **threatening** and **highly uncertain**.

**How can we accommodate/quantify the uncertainties so that we can get on with planning for the coming changes?**

Under various greenhouse forcings, climate models yield a fairly narrow range of warming scenarios and (amidst a broad overall range) a tendency for little precipitation change in California and most of the West.



PROJECTED CHANGES IN ANNUAL TEMPERATURE, NORTHERN CALIFORNIA

Business as Usual emissions
A2 emissions
B2 emissions
A1fi emissions
B1 emissions

*20 of 23 in this range*

PROJECTED CHANGES IN ANNUAL PRECIPITATION, NORTHERN CALIFORNIA

Business as Usual emissions
A2 emissions
B2 emissions
A1fi emissions
B1 emissions

*19 of 23 in this range*

Dettinger, 2005

Greenhouse forcings
1900-2100

Radiative forcing ( watts / m**2 )

*Using the historical (1950-99) record:*

Estimating influence of a uniform +3°C warming on **FREEZING SEASON LENGTH**

PROJECTED CHANGES IN ANNUAL TEMPERATURE, NORTHERN CALIFORNIA

- Business as Usual emissions
- A2 emissions
- B2 emissions
- A1fi emissions
- B1 emissions

NUMBER OF DAYS/YEAR WITH MEAN TEMPERATURES IN THE RANGE: -3C < Tavg < 0C
[from 1950-1999 VIC 1/8-degree INPUT DATA]

**Less vulnerable**          **More vulnerable**
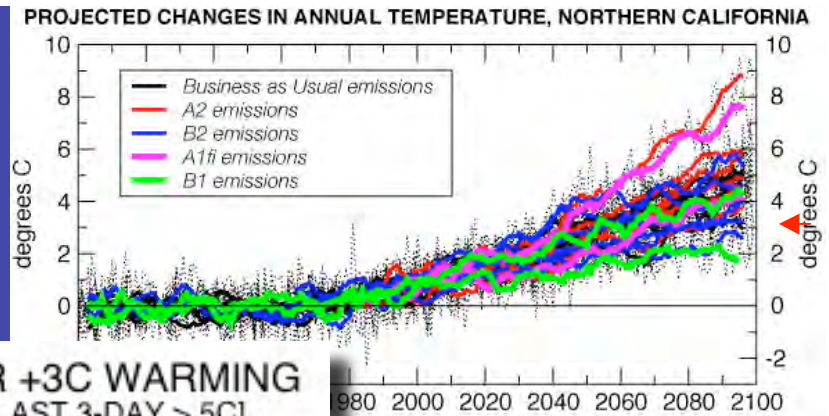
*"Freezing Season"*

DAYS PER YEAR
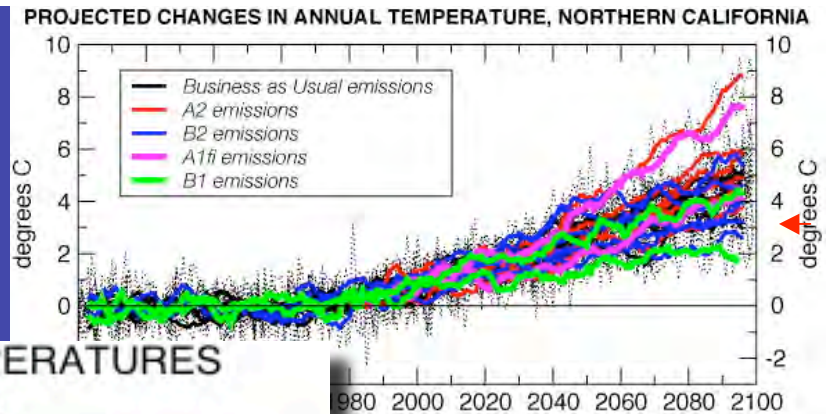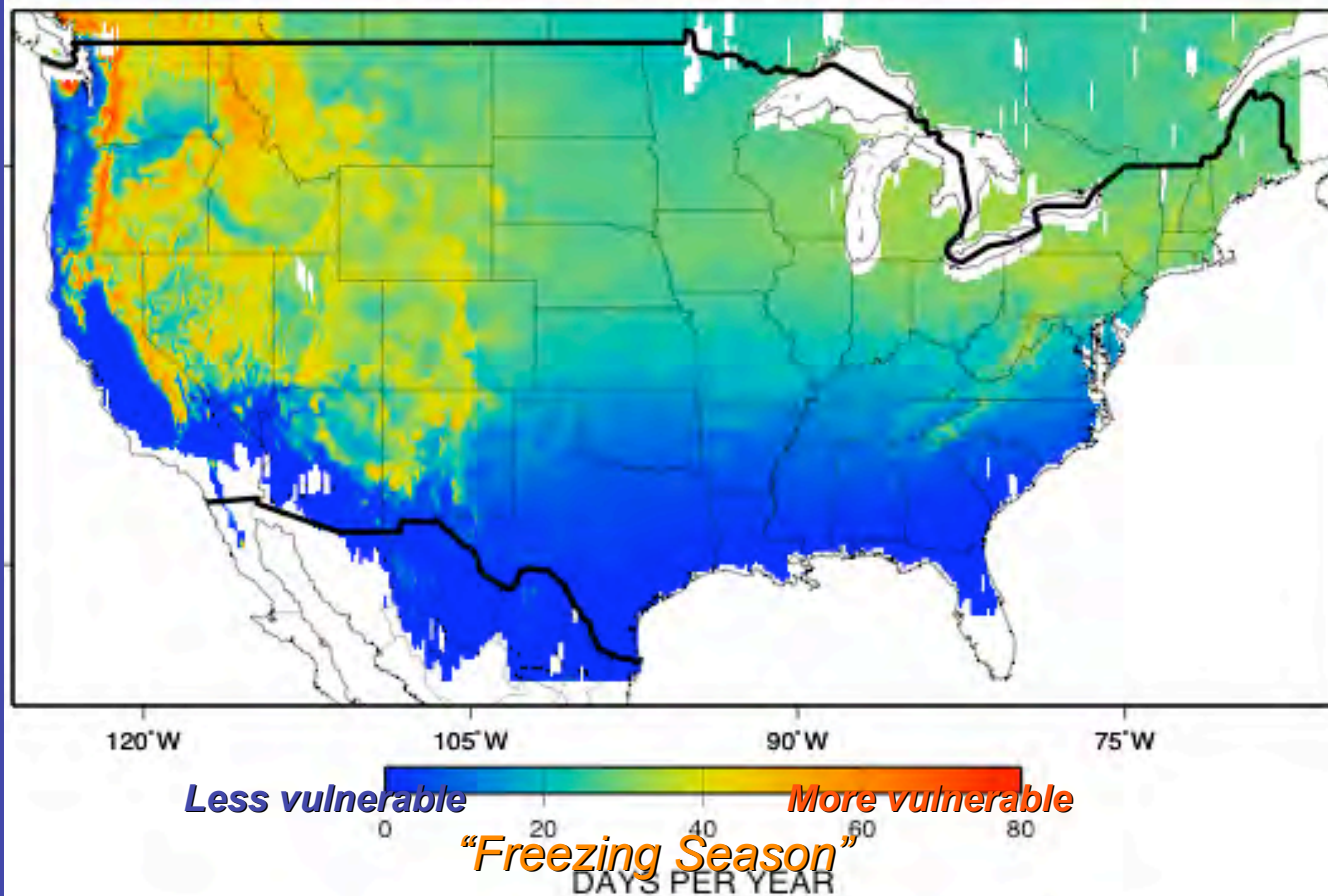
*Computed from UW's VIC model daily INPUTS (Nijsson et al, 2001), 1950-1999*

*from Bales et al., in review*

*Using the historical (1950-99) record:*

Estimating influence of a uniform +3°C warming on GROWING SEASON LENGTH
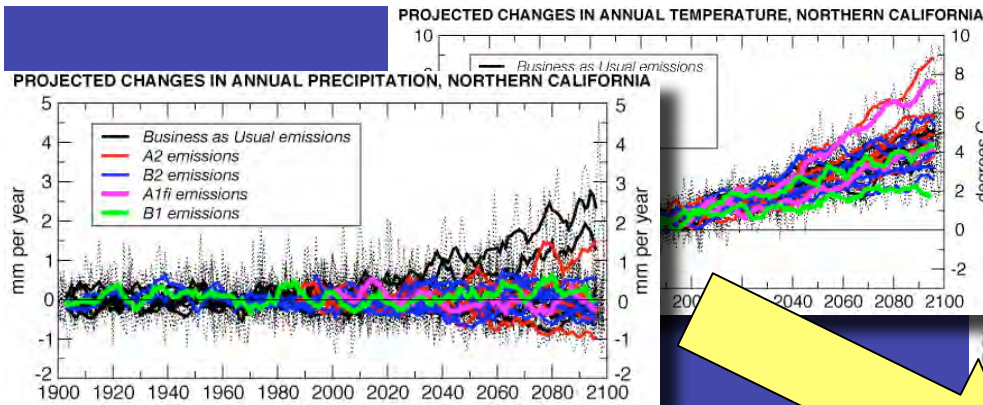
PROJECTED CHANGES IN ANNUAL TEMPERATURE, NORTHERN CALIFORNIA

- Business as Usual emissions
- A2 emissions
- B2 emissions
- A1fi emissions
- B1 emissions

CHANGE IN GROWING-SEASON LENGTH UNDER +3C WARMING
[GROWING SEASON = LONGEST INTERVAL FROM FIRST TO LAST 3-DAY > 5C]

Less vulnerable                    More vulnerable

*"Growing Season"*

DAYS LONGER
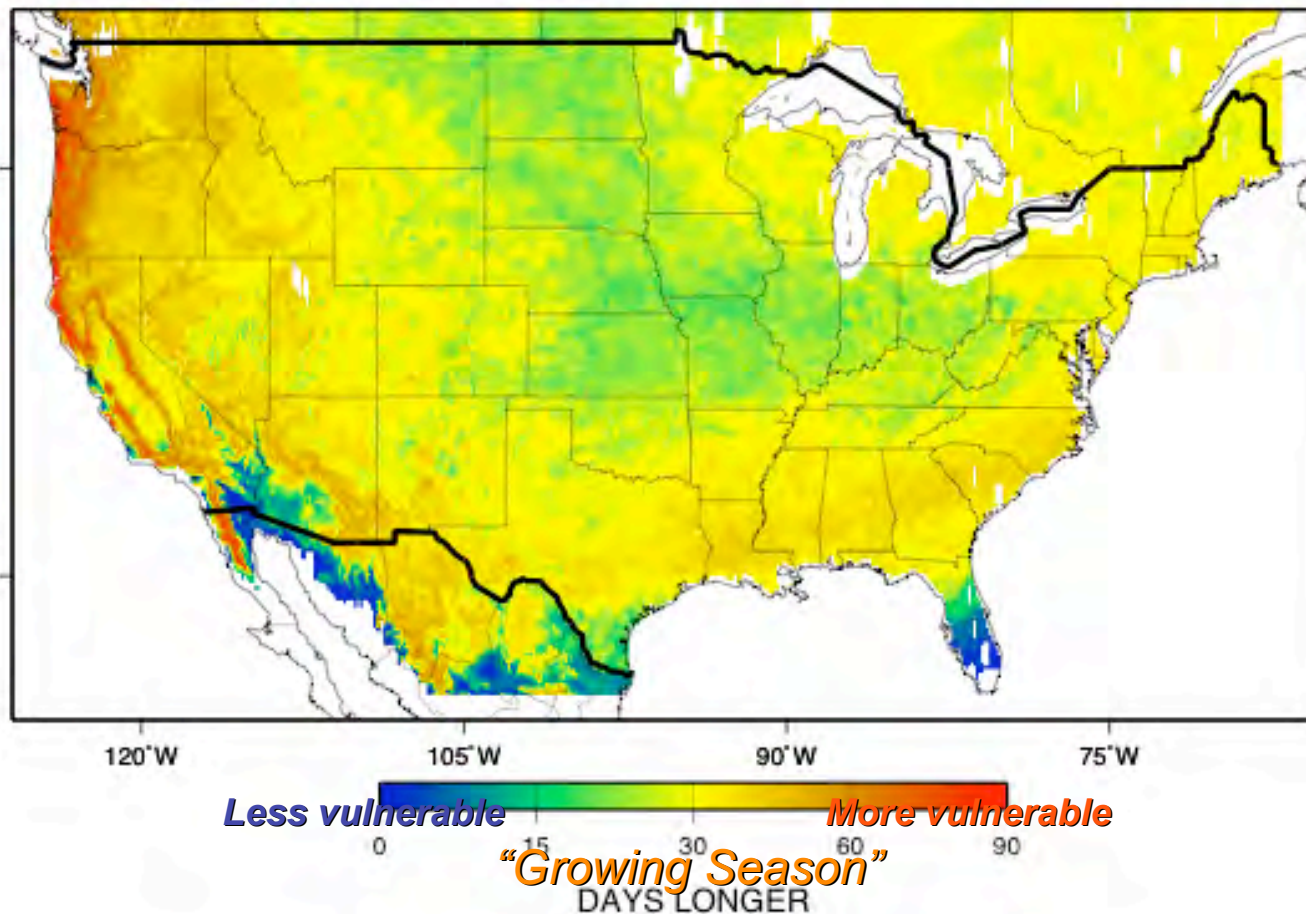
*Computed from UW's VIC model daily INPUTS, 1950-1999*

*from Betancourt et al., 2005, AGU Fall Mtg*

PROJECTED CHANGES IN ANNUAL TEMPERATURE, NORTHERN CALIFORNIA

PROJECTED CHANGES IN ANNUAL PRECIPITATION, NORTHERN CALIFORNIA

RESAMPLED PROBABILITY DISTRIBUTIONS
(from 6 GCMS, 3 SCENARIOS)
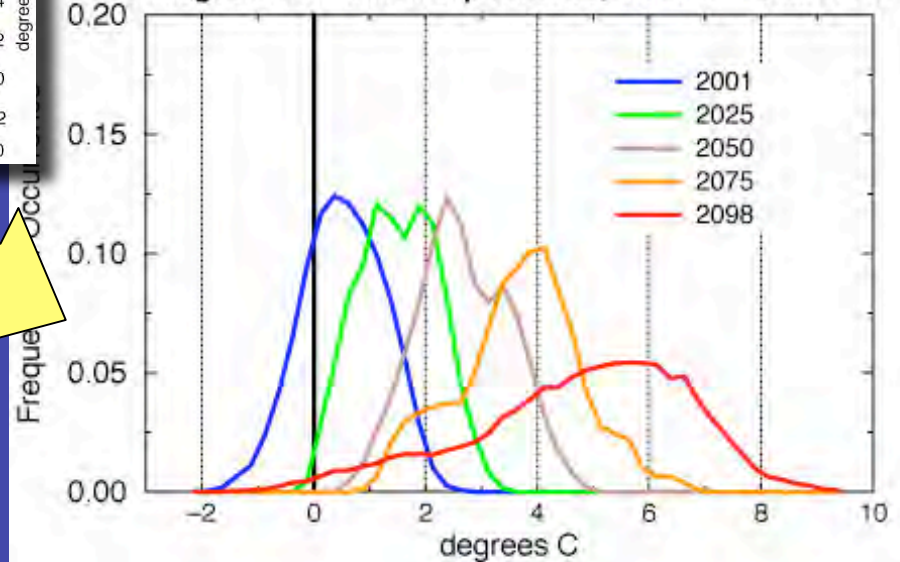Changes in Annual Temperatures, Northern California

If we fit probability distributions to this ensemble:

❖Important temperature (& snowmelt) changes within about 20 years

❖Strong tendency toward little precipitation change, with a hint of slightly drier (especially in southern CA)

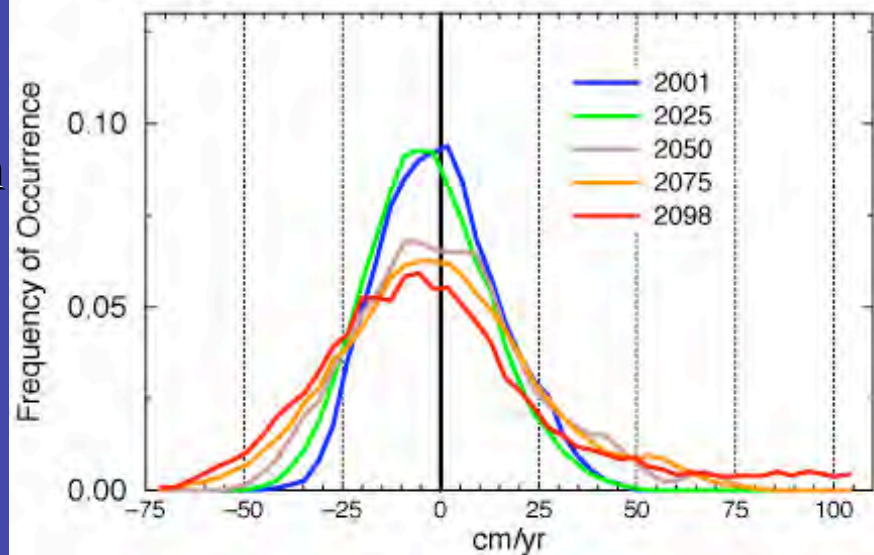❖General spreading of possibilities due to model and emissions uncertainties

*Dettinger, 2005, SFEWS ; in press, Climatic Change*

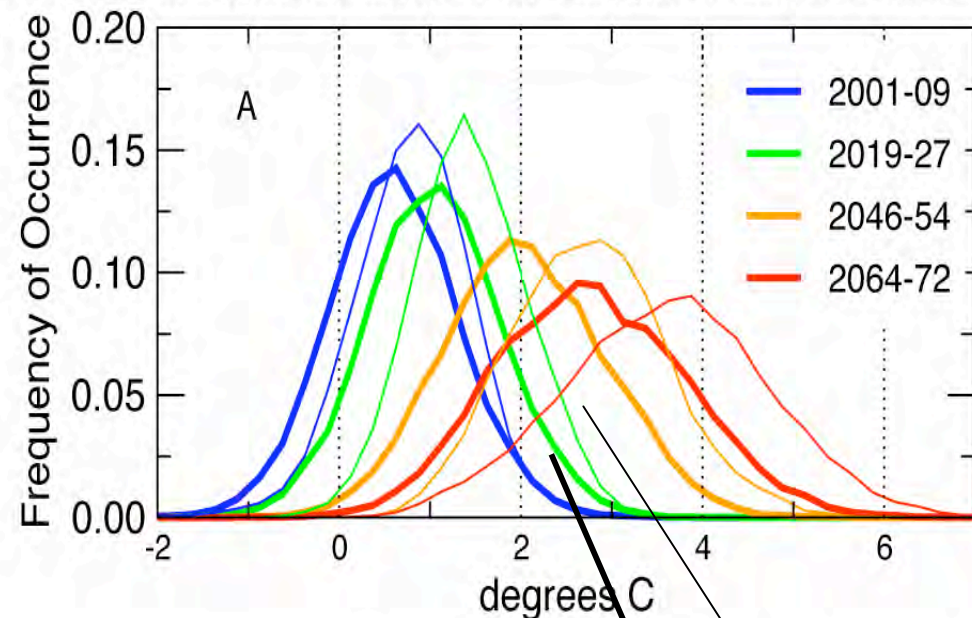Changes in Annual Precipitation, Northern California

# WHAT ABOUT THE NEW IPCC4 PROJECTIONS?

A new ensemble of 84 projections from 12 climate models yields few surprises (compared to the previous projections)!
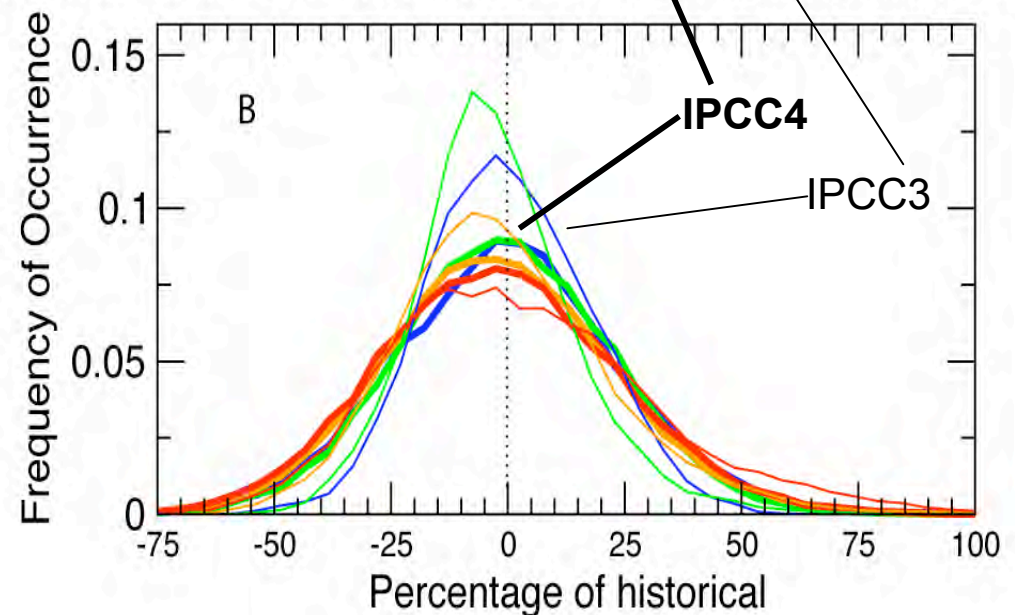
Light curves = earlier ensemble
Heavy curves = IPCC4 ensemble

*Dettinger, in review, GRL*



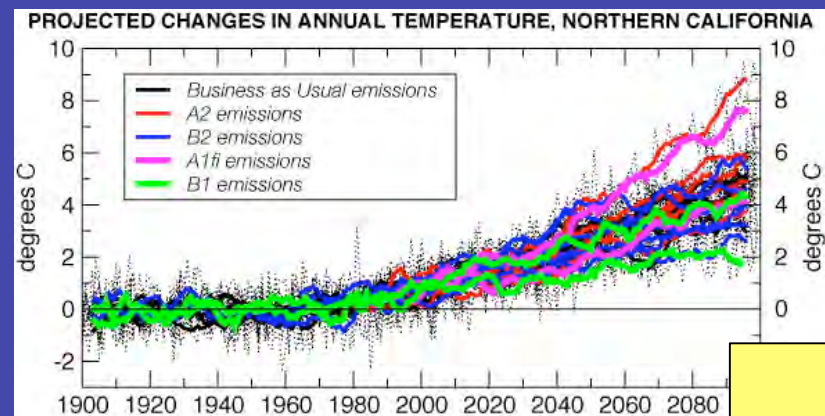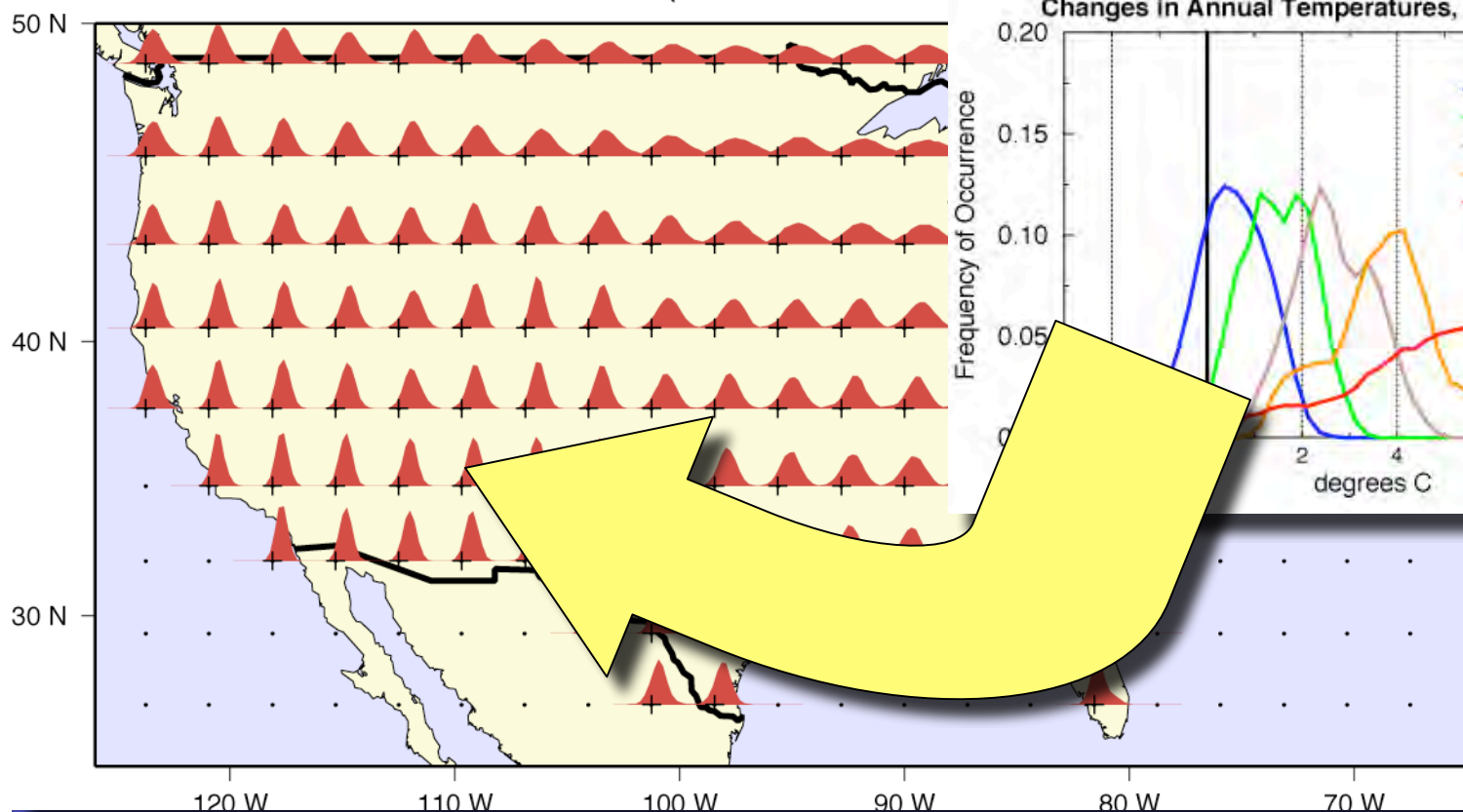CHANGES IN ANNUAL TEMPERATURE, NORTHERN CALIFORNIA

A

2001-09
2019-27
2046-54
2064-72

Frequency of Occurrence

degrees C

CHANGES IN ANNUAL PRECIPITATION, NORTHERN CALIFORNIA

B

IPCC4

IPCC3

Frequency of Occurrence

Percentage of historical

# A Natural Next Step is Estimation of **PDFs of CLIMATE CHANGE Across the US**

*(to summarize when, where, & how much climate change is being projected)*



PROJECTED CHANGES IN ANNUAL TEMPERATURE, NORTHERN CALIFORNIA

- Business as Usual emissions
- A2 emissions
- B2 emissions
- A1fi emissions
- B1 emissions



DISTRIBUTIONS OF MONTHLY-JANUARY TE...
PROJECTED FOR 2050 (FROM 1950-99...



RESAMPLED PROBABILITY DISTRIBUTIONS
(from 6 GCMS, 3 SCENARIOS)

Changes in Annual Temperatures, Northern California

- 20...
- 2050
- 2075
- 2098
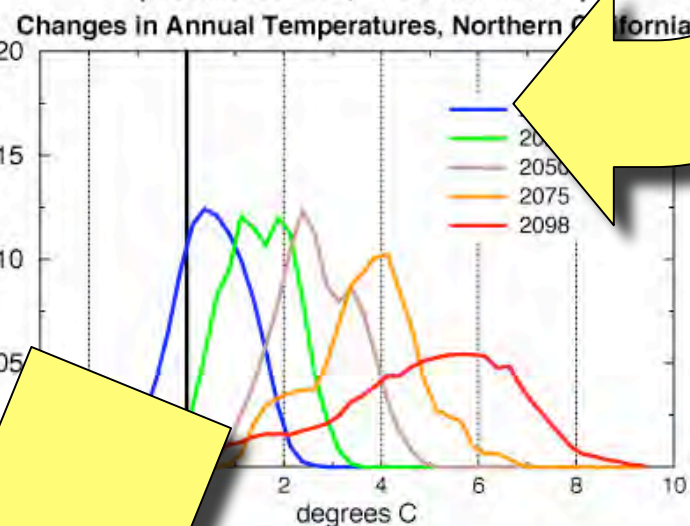
# Monthly Distributions of
# TEMPERATURE CHANGE PROJECTIONS for 2050



DISTRIBUTIONS OF MONTHLY-JANUARY TEMPERATURE ANOMALIES PROJECTED FOR 2050 (relative to1950-99 January means)
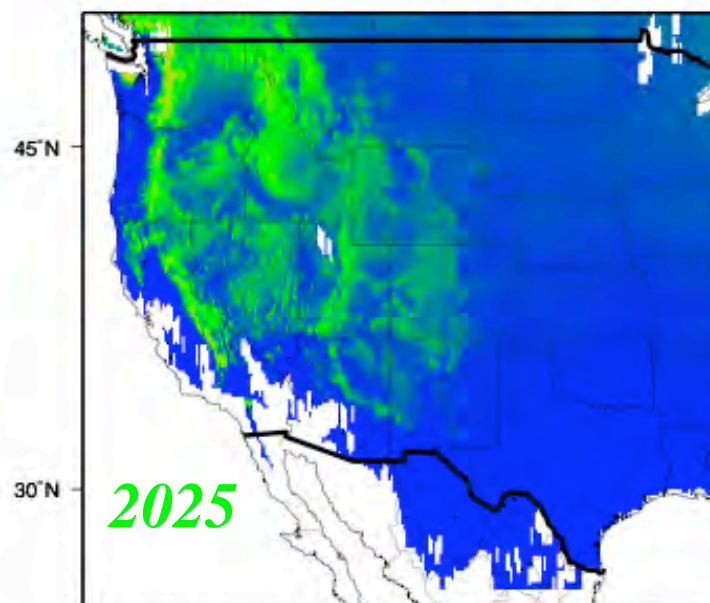
JANUARY 2050
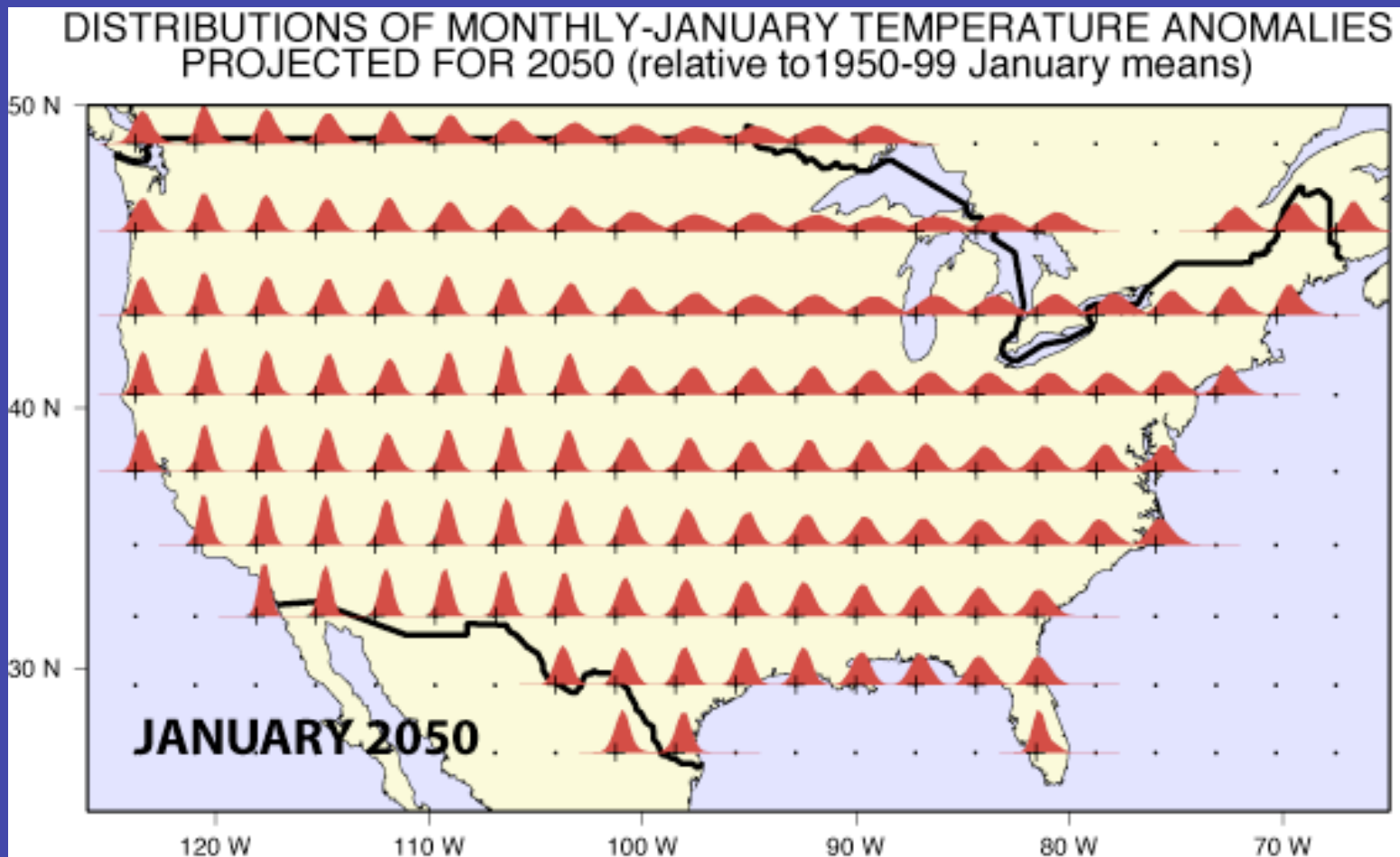
[All pdfs are scaled the same, with the horizontal bar under pdf in southern Florida ranging from -8.5 to +20C changes; dots and pluses indicate interpolated climate-model grid; pluses also mark the origins of each pdf (dT=0C)]

**…and then apply those pdfs to estimate "expected values" of warming effects on RAIN-vs-SNOW**
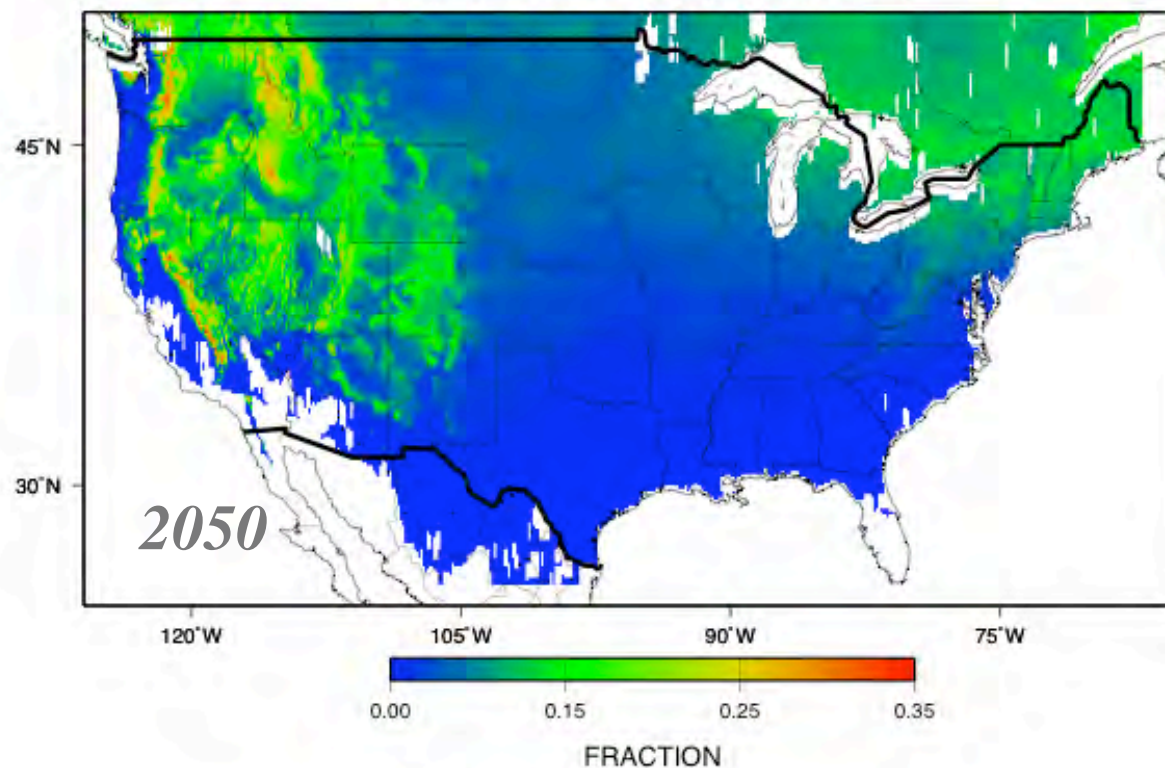
DISTRIBUTIONS OF MONTHLY-JANUARY TEMPERATURE ANOMALIES PROJECTED FOR 2050 (FROM 1950-99 JANUARY MEANS)
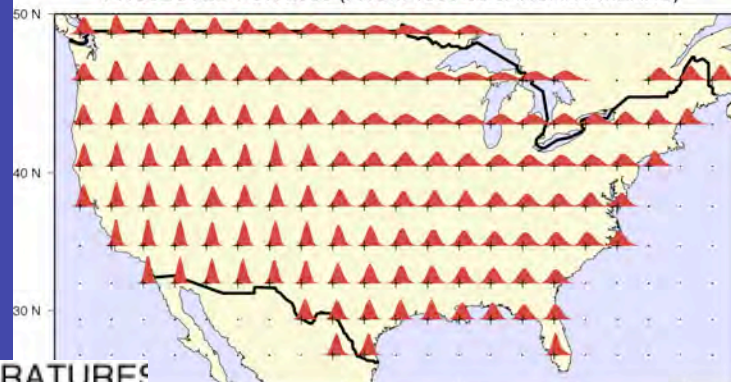
EXPECTED FRACTION OF ANNUAL PRECIPITATION WITH MEAN TEMPERATURES RAISED ABOVE FREEZING BY PROJECTED WARMINGS IN 2025
[from 1950-1999 VIC 1/8-degree INPUT DATA]

EXPECTED FRACTION OF ANNUAL PRECIPITATION WITH MEAN TEMPERATURES RAISED ABOVE FREEZING BY PROJECTED WARMINGS IN 2050
[from 1950-1999 VIC 1/8-degree INPUT DATA]
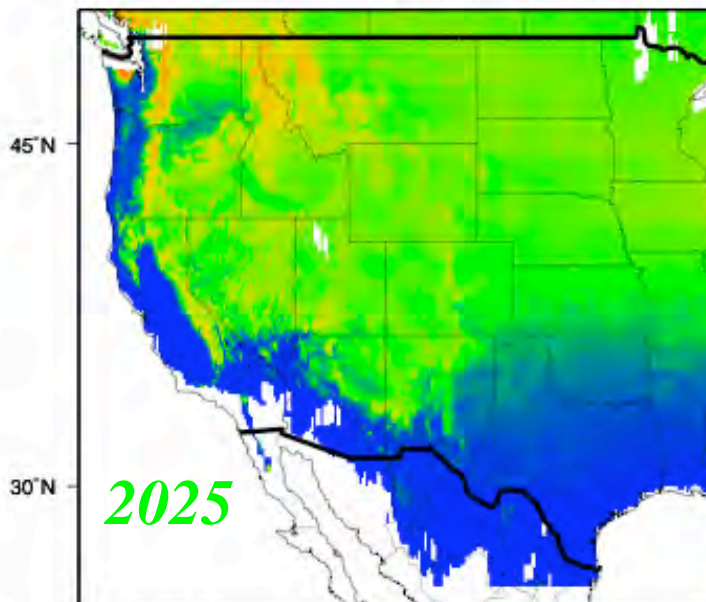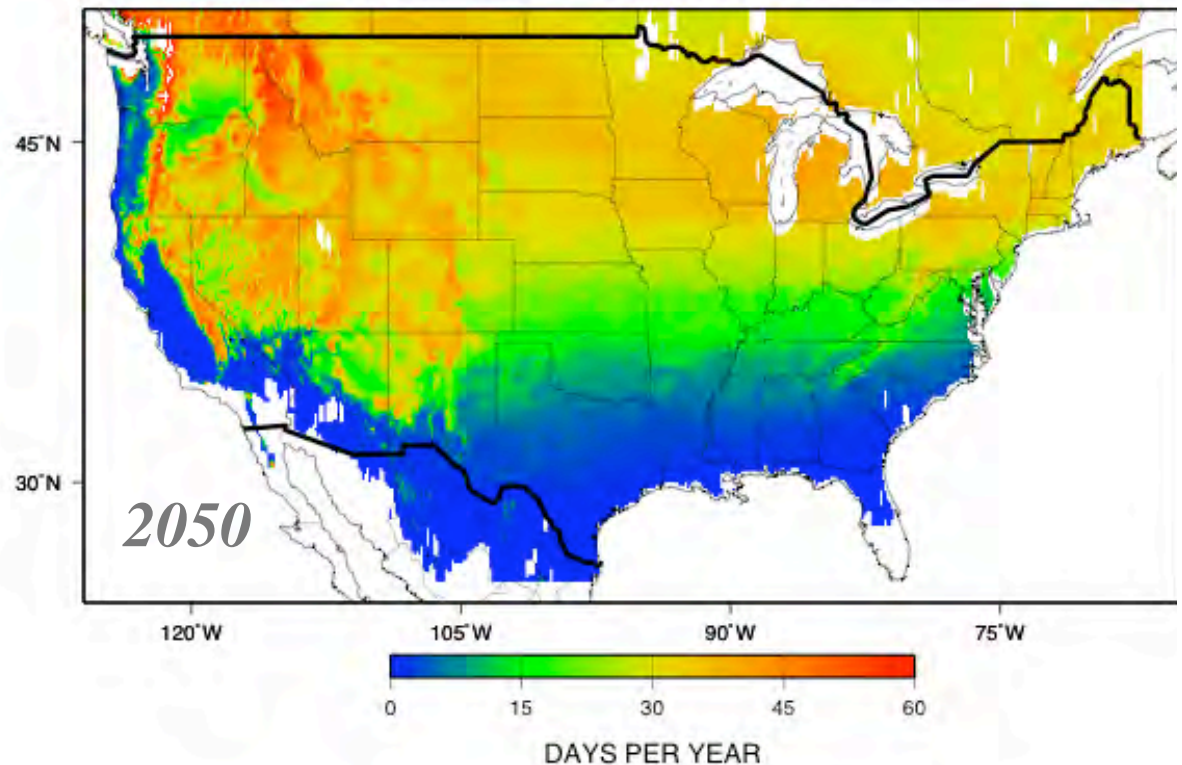
*2025*

*2050*

*Derived from monthly IPCC GCM-grid pdfs, and UW's VIC model daily inputs, 1950-1999*

USGS

FRACTION

**Expected values of changes in FROZEN-SEASON LENGTH**

DISTRIBUTIONS OF MONTHLY-JANUARY TEMPERATURE ANOMALIES PROJECTED FOR 2050 (FROM 1950-99 JANUARY MEANS)

EXPECTED NUMBER OF DAYS/YEAR WITH MEAN TEMPERATURES RAISED ABOVE FREEZING BY PROJECTED WARMINGS IN 2025
[from 1950-1999 VIC 1/8-degree INPUT DATA]

*2025*
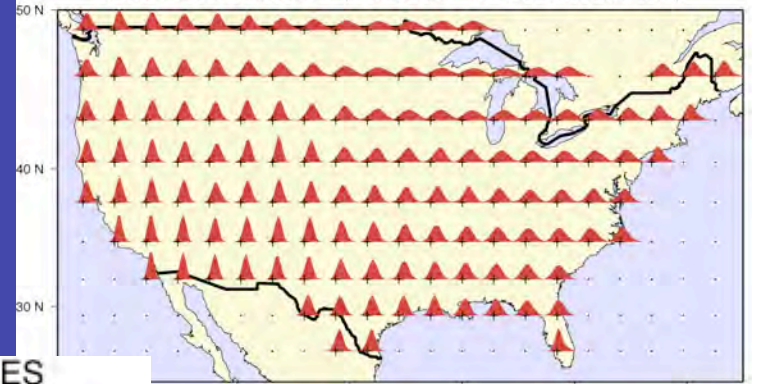
EXPECTED NUMBER OF DAYS/YEAR WITH MEAN TEMPERATURES RAISED ABOVE FREEZING BY PROJECTED WARMINGS IN 2050
[from 1950-1999 VIC 1/8-degree INPUT DATA]

*2050*

*Derived from monthly IPCC GCM-grid pdfs, and UW's VIC model daily inputs, 1950-1999*
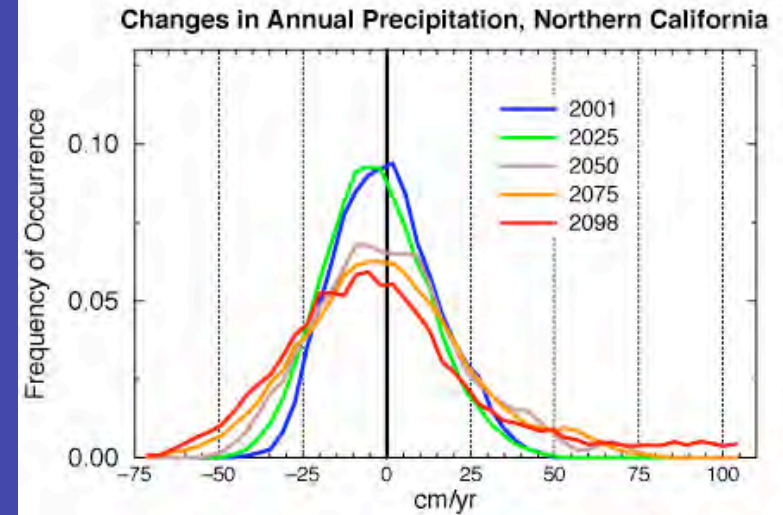
≈ USGS

DAYS PER YEAR

**Looking forward …**

**To paraphrase Myles Allen (Nature 2003):**



*"It is time for climate modelers to start identifying changes that can be ruled out as unlikely rather than simply ruled in as possible."*

**Or perhaps even…**

*It is time for California analysts to focus on what is most likely rather than what is just possible.*
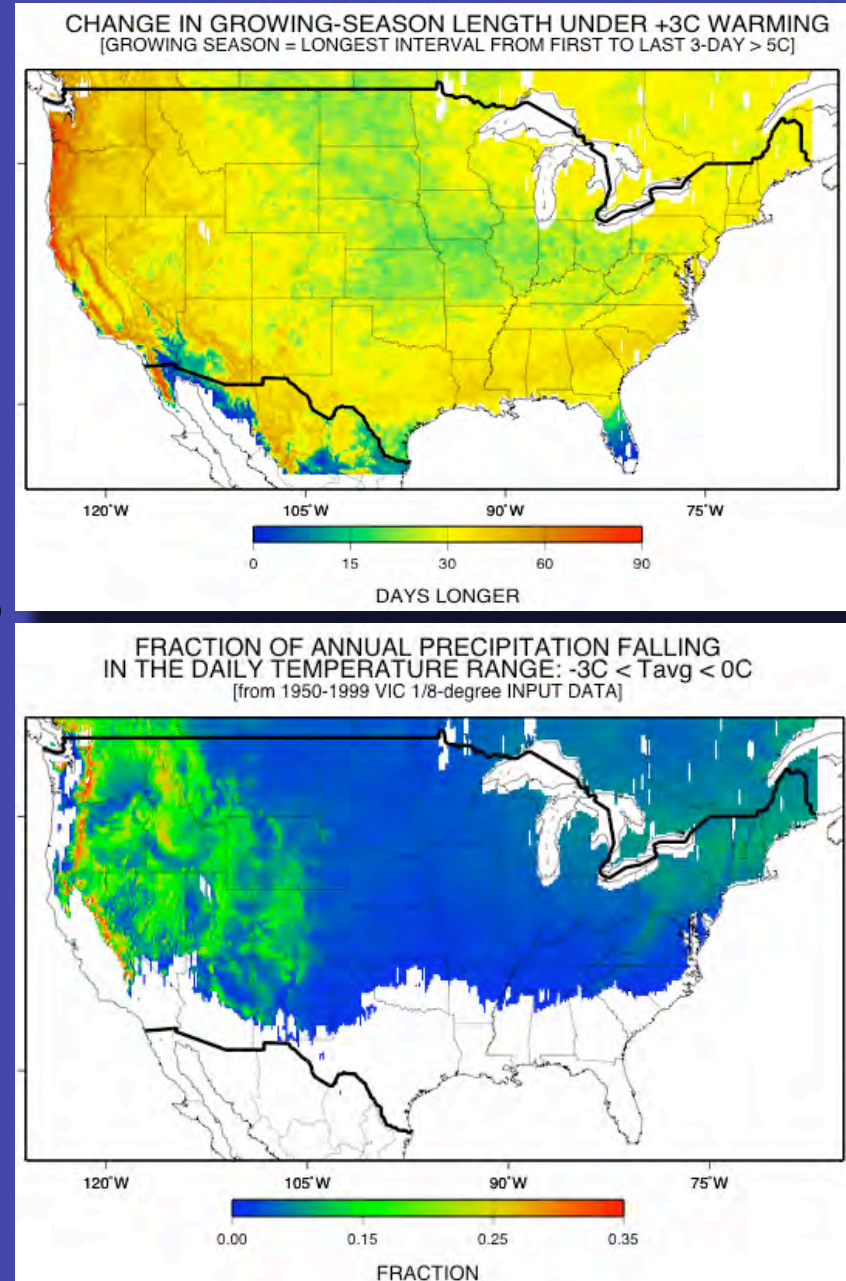
**Looking forward (#2)…**

*Even a simple exercise with historical meteorological records suggests:*

In the conterminous US, the Pacific Coast states are likely to be **MOST VULNERABLE** to hydrologic and growing-season influences of global warming!

The Pacific Coast states are also likely to be **VULNERABLE FIRST!**



CHANGE IN GROWING-SEASON LENGTH UNDER +3C WARMING
[GROWING SEASON = LONGEST INTERVAL FROM FIRST TO LAST 3-DAY > 5C]

DAYS LONGER



FRACTION OF ANNUAL PRECIPITATION FALLING
IN THE DAILY TEMPERATURE RANGE: -3C < Tavg < 0C
[from 1950-1999 VIC 1/8-degree INPUT DATA]

FRACTION

DISTRIBUTIONS OF MONTHLY-JANUARY TEMPERATURE ANOMALIES PROJECTED FOR 2050 (FROM 1950-99 JANUARY MEANS)

**Looking forward (#3)…**

**We are going to need:**

• More complete probabilistic descriptions of projected futures

• Downscaling methods that seamlessly reflect probabilistic projections

• Strategies for injecting probabilistic projections into impact/response analyses, without requiring massive Monte Carlo simulations
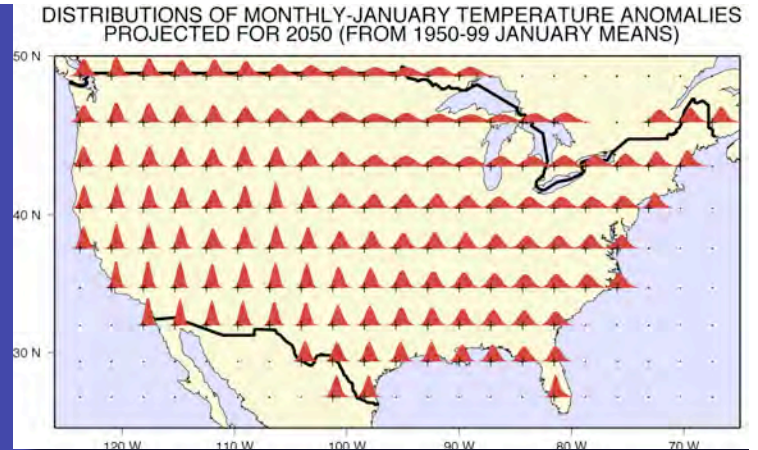
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